Fault at Waimea, Oahu

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INTRODUCTION

THIS PAPER IS PLANNED to show that a fault cuts the shore line of the island of Oahu at Waimea Bay, 7 miles southwest of the north point of the island. It is thought that this is the first time that a fault of appreciable offset has been unequivocally detected in the island of Oahu.

Stearns (1935: 82, 173, 414) makes little mention of faults in his comprehensive report on the geology of Oahu. He thinks that a certain cliff in the Waianae Range, buried by later lava flows, may have been caused by faulting, although he says that the cliff may well have some other origin. He also describes several minor faults.

In regions underlain by extensive, uniform beds of rock, faulting is often manifested by an offsetting of readily identifiable layers along the surface of fracture. In many places the offsets may be seen on valley sides or in artificial excavations. This type of evidence of faulting is not applicable in Hawaii because the individual lava flows vary so much in texture and in thickness that they are not readily identifiable. Continuous tracing of an individual flow is of little use because most flows are rather narrow, and not extensive.

In the uneroded, younger parts of the Hawaiian Islands, bold cliffs have been made by faulting. The block of rock on one side of the fault has been dropped, so that a bold cliff leads up from the edge of the dropped block to the edge of the stationary or relatively raised block. The infacing cliffs at Kilauea and the cliffs that cut the shore line of the island of Hawaii at South Point and at Kealakekua Bay are almost certainly such fault cliffs.

In the strongly weathered and eroded older parts of the Hawaiian Islands, any fault cliffs that may have existed formerly have become much subdued and are no longer conspicuous features of the landscape. The existence of such faults can be demonstrated only by less direct evidence.

In the present paper the hypothesis is adopted that a fault extends inland from Waimea Bay in a direction a little south of east, and that the block on the north side has been raised relative to the block on the south side. Several consequences of this hypothesis are deduced, and the consequences are found to agree with features actually existing in this part of Oahu.

I am greatly indebted to Dr. Chester K. Wentworth and to Dr. A. Grove Day for carefully reading the manuscript and giving me valuable suggestions for its improvement.

OFFSETTING OF THE SHORE LINE

Where a coastal region has a seaward sloping surface, and is cut by a fault at a large angle to the shore line, the block that is relatively raised will have its shore line shifted seaward. This kind of offsetting is diagrammatically illustrated in Figure 1, in which the upper sketch represents a dome-shaped island, such as the Hawaiian volcanoes build. The lower sketch shows a similar dome cut by a fault perpendicular to the shore line. The block on the left is the upthrown side and has its shore line displaced seaward from

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the shore line on the right, or downthrown, side. The accompanying maps of the Waimea, Oahu, region (Fig. 2 and 5) show that the shore line has a general trend from northeast to southwest, but that the part northeast of the bay, if continued southwestward, would lie about two thirds of a mile seaward of the southwestern part of the shore line. A fault at Waimea would result in this sort of offsetting of the shore line.

OFFSETTING OF RESTORED CONTOUR LINES

The volcanic domes sketched in Figure 1 have topographic contour lines drawn on them, and it will be noted that on the faulted

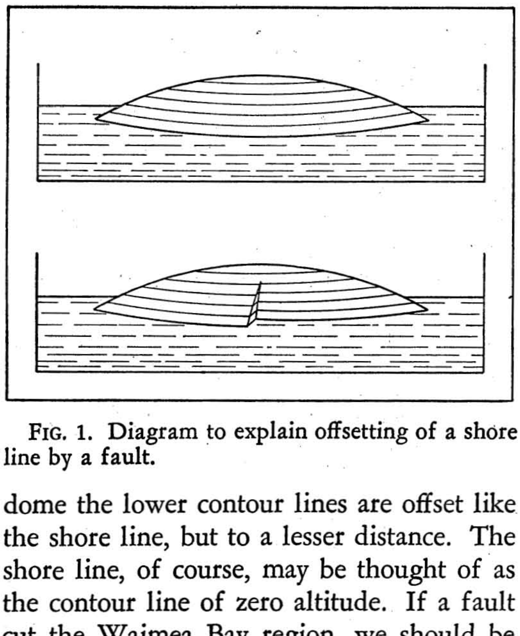

FIG. 1. Diagram to explain offsetting of a shore line by a fault.

dome the lower contour lines are offset like the shore line, but to a lesser distance. The shore line, of course, may be thought of as the contour line of zero altitude. If a fault cut the Waimea Bay region, we should be able to find traces of offsetting of some of the contour lines.

Figure 2 was prepared by tracing as light lines the 500-, 1,000-, 1,500-, and 2,000-foot contour lines from a topographic map of Oahu (U. S. Geol. Survey, 1938) as the first step. The contour lines of the original map were slightly smoothed and generalized in tracing. Next, smoothly sweeping, curved, heavy lines were drawn so as to be tangent

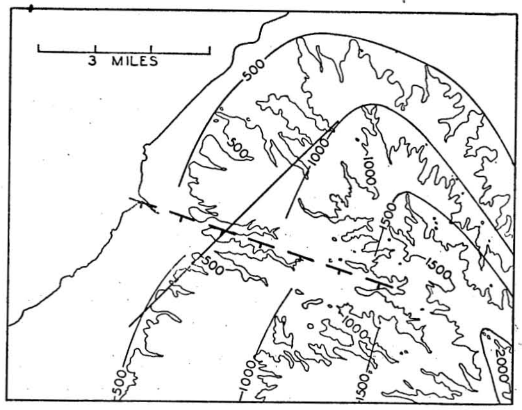

FIG. 2. Generalized contour map of the Waimea, Oahu, region. The light lines are the present-day contour lines; the heavy, smoothly curving lines are restored contour lines; the heavy, broken line shows a reasonable course of the fault, with spurs extending toward the downthrown side; and the straight, heavy line is the line of the profile of Figure 6.

to the seaward salients of the actual contour lines, and thus to form "envelopes" around the present-day contour lines. These smooth, restored contour lines show approximately the shape of this part of the Koolau volcanic dome as it was before dissection by stream erosion had roughened it. The restored contour lines at 500, 1,000, and 1,500 feet have their northeastern parts offset seaward with respect to their southwestern parts in the same way that the shore line is offset, and, presumably, for the same reason.

The precise course of the fault is obscured, but the heavy, broken line of Figure 2 shows a reasonable approximate position. The short lines perpendicular to the several segments indicate the downthrown side of the fault.

HEIGHTS OF WAVE-CUT CLIFFS

Volcanic domes are subject to erosion by streams and by waves. If we neglect the work of streams for the moment, and consider only the work of waves, we realize that the sloping shores would become cliffed, as is suggested in the upper sketch of Figure 3. The sketch cannot show it, but the cliff would continue below sea level a short distance, and a wave-cut bench would extend seaward from the foot of the cliff. If after the cutting of the cliff the dome-shaped island were faulted, the cliff along the raised part would of course have its crest higher than the cliff crest on the lowered part, as is suggested in the lower sketch of Figure 3. If there were in addition a lowering of sea level or a raising of the whole island, the wave-cut bench might be exposed and would be higher on the upthrown block than on the downthrown block.

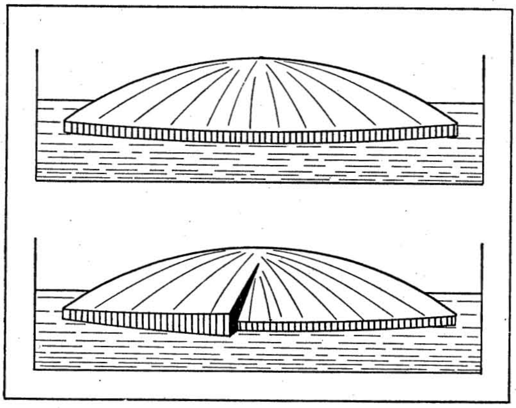

FIG. 3. Diagram to explain how a fault may change the height of sea cliffs.

At some time in the past, waves cut conspicuous cliffs along this part of the shore line of Oahu, just as waves have cut the present striking cliffs along the Hamakua Coast of the island of Hawaii. Later a lowering of sea level exposed the wave-cut bench, on which reefs had been built in the meantime by corals and associated organisms. Streams carrying detritus from inland have built alluvial slopes on the emerged platform. As one drives along Kamehameha Highway, which is on the platform and in general fairly close to the shore, one can see that the wave-cut cliffs are decidedly higher northeast of Waimea Bay than southwest of the bay. This difference in heights of cliffs agrees with the hypothesis of a fault at Waimea Bay.

CONCENTRATION OF PERENNIAL DRAINAGE

Streams on a symmetrical volcanic dome tend to take courses that radiate from the central summit, somewhat like the spokes of a wheel, as is suggested by Figure 4, a

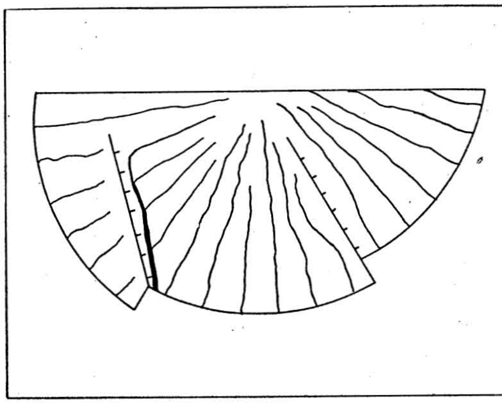

FIG. 4. Diagrammatic map to explain the concentration of drainage by a fault.

diagrammatic map of the stream courses on half of a dome-shaped island. But if the island is faulted, some of the stream courses may be diverted, as is shown at the left in Figure 4. The fault is shown by a straight line with short perpendicular lines on the downthrown side. The fault is seen to divert the headwaters of four streams into one course, which is thereby given an unusually large volume of water and an increased ability to erode. This appears to be what has happened at Waimea Canyon, Kauai, where the stream has cut that remarkably deep canyon. The lowering of the stream bed, partly by downfaulting and partly by its own erosion, has brought it closer to the water table, so that the stream is more generously fed by underground water at all times, and receives some ground water even in the drier seasons.

At the right in Figure 4 another fault is shown, but one about perpendicular to the shore line. Since the course of this fault is radial and essentially parallel to the radial stream courses, it does not concentrate stream flow to an appreciable extent. The situation at Waimea, Oahu, would seem to be midway between these two types, for our hypothesis supposes a fault only moderately oblique to the shore line.

When Figure 5 was drawn, all the stream

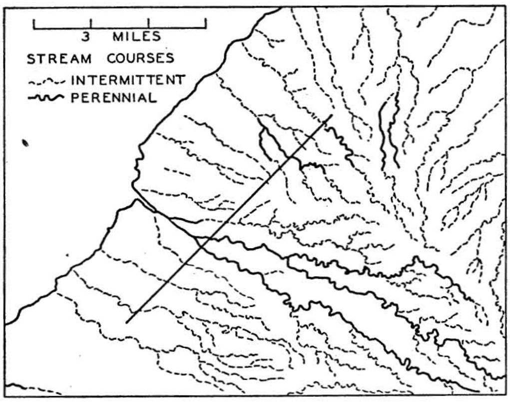

FIG. 5. Drainage map of the Waimea, Oahu, region, showing the concentration of perennial reaches of the streams near the fault.

courses of the region were traced off from the topographic map. Some generalization resulted during the process of tracing. The intermittent reaches of the streams are shown as broken lines and the perennial reaches are shown as heavier, continuous lines. Except in the southeast corner it would be hard to find a point more than a third of a mile away from some stream course, which amounts to saying that the region has been rather intricately cut up into valleys and ridges.

The perennial reaches of the streams, however, show a decided concentration inasmuch as the three that are longest lie rather close to one another and rather close to the position of the suggested fault. The concentration of perennial courses is another item that agrees with the present hypothesis.

PROFILE ACROSS WAIMEA

The heavy, straight lines extending from northeast to southwest in Figures 2 and 5 show the line along which the profile of Figure 6 was constructed. The profile was prepared from the preliminary sheets of the most recent topographic map of Oahu (U. S. Geol. Survey, n.d.), with a horizontal scale of a little over 3 inches to the mile. The vertical scale of Figure 6 is a little over four times as large as the horizontal scale. It will be seen that the high parts of the profile to the left (northeast) of Elehaha Stream are at altitudes around 800 feet, whereas those to the right (southwest) of Kaiwikoele Stream are about 200 feet lower. This difference would result from the vertical offsetting of the two blocks by the suggested fault.

TWO-CYCLE TOPOGRAPHY ON THE UPTHROWN BLOCK

Where the earth's crust is stable, a stream will at first cut a rather narrow and deep valley, but as time goes on the valley becomes wider and more flaring because the rocks of the valley sides weather, become weak, and gradually slump or creep toward the stream. Thus a wider valley, with more gently sloping sides, will be made.

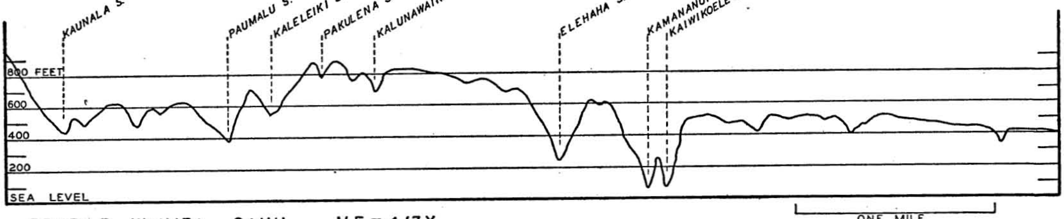

FIG. 6. Topographic profile of the Waimea, Oahu, region, parallel to the shore line.

If the region is later raised, or tilted, so that the stream is given a steeper gradient and a great velocity, the stream will revert to a predominance of deepening over widening, and will cut a new, inner, narrow valley along the trough of the older, outer, broader valley. This process results in what is known as "two-cycle topography," or "valley-in-valley topography," characterized by the break in the transverse profile where the upper and lower valley sides meet. The upper valley was cut during an earlier cycle of erosion and the lower valley during a later cycle.

The hypothesis that there is a fault at Waimea supposes the block on the northeast to have been raised. If this is true, the raising should have rejuvenated the streams and should have produced two-cycle topography. Such topography is found between Pupukea and Kaunala, in an area extending for about 3 miles parallel to the shore line, and lying inland from the crest of the wave-cut cliff. Unfortunately the contour intervals of the maps do not permit constructing a profile that will show the inner and outer valleys. In Figure 7, the inner valley runs from right to left. The photographer stood on a part of the older, upper valley slopes which extend to the middle distance. The pineapple fields on the far side, and the pasture to the right of the pineapple fields, are also on the older, upper valley slopes. The sides of the younger, inner valley are too steep to be tilled, and are partly in brush, partly in grass, and partly bare of vegetation.

THE FAULT SCARP

Where faulting has recently raised one crust block with respect to the adjacent block, a cliff or fault scarp separates the two blocks, and at first is likely to be a conspicuous feature of the landscape. As time goes on, however, the scarp becomes weathered and eroded back, and changes into a more or less subdued and inconspicuous land form. Such is the scarp of the Waimea fault, now that it is rather old. The best place known to the writer from which to view this subdued scarp is the bridge across the small Lauhulu

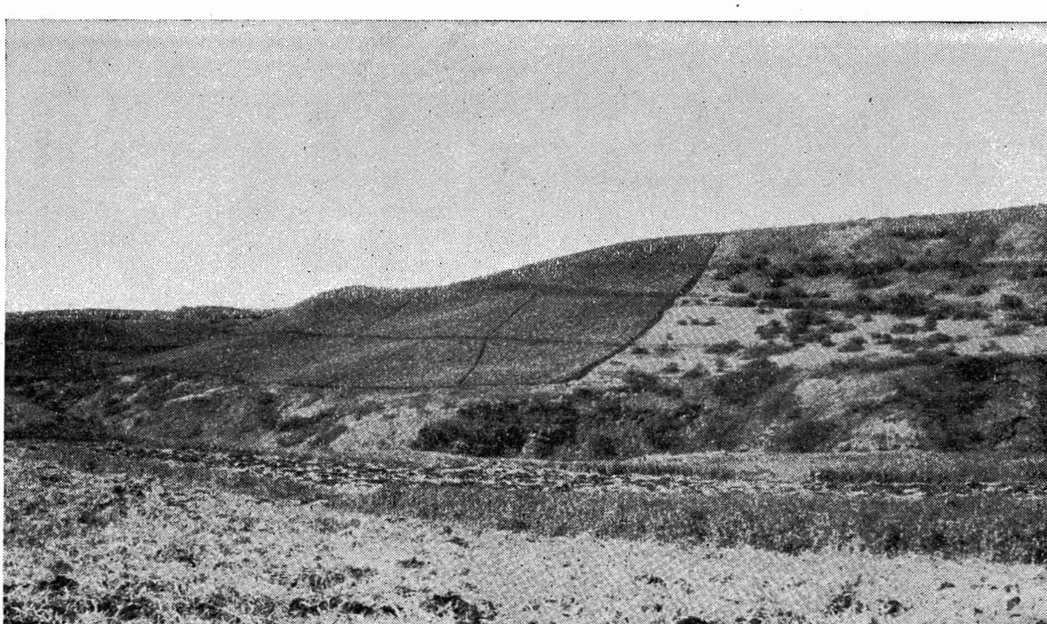

FIG. 7. View of two-cycle or valley-in-valley topography on the upthrown fault block.

Stream, 2.1 miles from Anahulu Bridge at Haleiwa, along Kamehameha Highway, toward Waimea Bay. Figure 8 was photographed from this point. To the right is the old, wave-cut cliff. The cliff leads up to fields of sugar cane, which show up in a rather light shade. The cane fields are on the top of the downthrown block. Beyond the

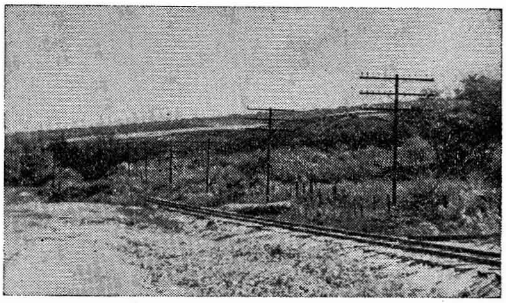

FIG. 8. Distant view of the eroded and subdued scarp of the Waimea, Oahu, fault, from Lauhulu Bridge, looking northeastward.

cane fields (and, in the picture, above the cane fields) is the eroded and subdued scarp of the upthrown block, marked by the darker shade of the trees that grow on it. The picture, of course, cannot show Waimea Valley, but it lies between the cane fields and the wooded slope. Valleys that are due solely to erosion will normally have ridges of the same height on both sides, but since the northeast side of Waimea Valley rises some 200 feet higher than the southwest side, the valley is not solely the product of stream erosion.

DIRECTION OF MOVEMENT

A fault scarp results from the vertical movement of the block of rock on one side of the fault relative to the block on the other side. If one block is actually stationary, the other may move either up or down; or it may be that both blocks move but that one moves farther than the other; or the two blocks may move in opposite directions.

At most of the faults in the Hawaiian Islands the higher block seems to have remained relatively stationary while the lower block moved downward, probably as a result of the removal of support from below. The infacing fault scarps at Kilauea, for example, are thought to have resulted from subsidence of the central block at times when the magma column has receded. The last event of this sort was in May, 1924, when the diameter of Halemaumau, the inner pit, was increased from about one third of a mile to about two thirds of a mile, by the engulfment of the central part, leaving a scarp of sheer cliffs several hundred feet high. A month earlier, subsidence along a fault at Kapoho near the east point of the island of Hawaii made a scarp 8 to 12 feet high, and the sea flooded a part of the block that dropped downward. Numerous other examples of presumed downward movement of fault blocks in Hawaii could be cited.

It is the writer's opinion, however, that at the Waimea, Oahu, fault the lower block remained relatively stationary while the higher block was actually raised, because this assumption appears to be called for by the two-cycle topography on the higher block.

Two-cycle topography results when a region that is fairly well advanced in the erosion cycle has its streams rejuvenated by having their gradients increased. This increase of gradient might be due to either (1) a lowering of sea level or (2) a raising of the land area. If the rejuvenation in question were due to a lowering of sea level, then similar rejuvenation and similar two-cycle topography should be found in many of the older parts of the Hawaiian Islands. In contrast, if the rejuvenation were due to unique uplift of this particular bit of Oahu, other parts of the Hawaiian Islands would not be rejuvenated and would not develop two-cycle topography. Inasmuch as the writer knows of no other places with similar two-cycle topography, he concludes that uplift of the higher, or northeastern, block took place.

The writer freely admits that he cannot show the mechanism by which the northeastern block was raised. A tentative suggestion is that a considerable body of molten matter was intruded under this block, perhaps at the time of the eruptions at Diamond Head and at numerous other young vents in the southeastern part of the Koolau Range.

CONCLUSION

It is not to be expected that one can detect faults in Hawaii by the offsetting of lava flows, because the individual flows are of small lateral extent and because there is great variation in texture and thickness from place to place within each lava flow.

It is believed that faulting occurred at Waimea, Oahu, because this region shows a number of features that would have resulted from faulting, and for which no other explanation comes to mind. These features include:

1. Offsetting of the shore line.
2. Offsetting of the restored contour lines.
3. Higher wave-cut cliffs on the upthrown side.
4. Concentration of perennial stream courses near the fault.
5. A step in the profile across the fault.
6. Two-cycle topography on the upthrown block.
7. A subdued scarp such as prolonged erosion would make of a fault cliff.

The cumulative evidence of these features seems to indicate faulting, although actual offsetting of the rock layers has not been found.

REFERENCES

STEARNS, HAROLD T., and KNUTE N. VAKSVIK. *Geology and ground water resources of the island of Oahu, Hawaii.* 479 p., 34 fig., 33 pl. Ter. of Hawaii, Div. Hydrog., Bul. 1, 1935.

U. S. GEOL. SURVEY. Advance sheets of Haleiwa, Kaipapau and Laie quadrangles of the topographic map of Oahu. Surveyed in 1929 and 1930. Scale 1:20,000; contour intervals 10 and 50 feet. [n.d.]

U. S. GEOL. SURVEY. Topographic map of the island of Oahu, City and County of Honolulu, Hawaii. Scale 1:62,500; contour interval 100 feet, 50-foot contour added. 1938.